IPPC Model Synthesis Summary – Oct. 18, 2019 vers. 1.0
Bronze Birch Borer Phenology (degree-day) Model ***Agrilus anxius* Gory** **(Coleoptera: Buprestidae)**
Developed by Len Coop for use at Oregon State University's Integrated Plant Protection Center website: https://uspest.org/wea

This is an insect attacking and emerging from logs and timbers of birch (Betula spp.). Imported birch species tend to be more susceptible than native birch.



photo credits: OSU Ken Gray Image Collection, https://oregondigital.org/sets/ken-gray

Bronze Birch Borer Model Parameters:

Lower threshold: 43 degrees F (6.1 degrees C)
Upper threshold: 100 degrees F (37.8 degrees C) (nominal – none determined)
Start Date: Jan. 1st
Calculation Method: single sine
Model based on several sources, primarily Akers and Nielsen (1984), Muilenburg and Herms (2012), and four others.
Region of known use: Data and observations used for model development from Ohio, Michigan, Kentucky, Indiana, and Illinois
Validation status: A few observations from 5 states are in accordance with model predictions. Otherwise largely unvalidated. The model itself is based on multiple years data from those states, some of which are approximate average date-based estimates

Table 1: Events and degree-days used in bronze birch borer (BBB) model:

Event	DDs (F)	DDs (C)
Prepupal larvae in overwintering cells in bark	250	139
Beginning of pupation	400	222
End of pupation	700	389
First adults exit trees	750	417
10% adult emergence	950	528
50% adult emergence	1100	611
Beginning of egg hatch and larval tunneling	1400	778
90% adult emergence	1600	889
Adult activity and egg hatch ended, larvae continue tunneling	2050	1139

Source #1: **Akers, RC and DG Nielsen. 1984. Predicting *Agrilus anxius* Gory (Coleoptera: Buprestidae) adult emergence by heat unit accumulation. JEE 77:1459-1463.**

Notes:
- OW usually as full grown larvae in pupal cell (or as young larvae if a 2 year life cycle)
- pupation in Ohio from late April to early May (Neiswander 1966)
- Main models were developed from Columbus and Wooster Ohio 1981-83 data, other locations were used for validation
- focused analysis on 10% emergence by monitoring exit holes in cut logs from European white birch (Betula pendula Roth).
- developed different lower thresholds and starting date models for data from Columbus and Wooster. The models therefore cannot be considered regionally robust.

Methods: Re-analyze data from Tables 2 and 3, Figs. 1 and 2 using available data sources:

1. Most daily Tmax and Tmin data from PRISM Data Explorer, http://prism.oregonstate.edu/explorer Data available back to 1981.
2. For 1979 and 1980 data, use Climate Engine, https://clim-engine.appspot.com/climateEngine
3. Batch calculate single sine DDs using uspest.org custom DD calculation program available from: https://uspest.org/ipm/run_batch_dds2.pl and https://uspest.org/ipm/utilities.pl example calculation run:

./run_batch_dds2.pl station=COLUMOH year=1981 calc=S1 start=01-01 end=05-30 tlow=42 tlowmax=52 thi=100

(NOTE: either extensive modifications or a login at uspest.org may be required to run this program)

Results from this example can be found in first row of data in Table 2 below

Table 2. Degree-days and C.V. for 10% adult emergence of bronze birch borer, using data from Tables 2 and 3 of Akers and Nielsen 1984; plus 1998 Wooster (source below):

Estimated weather Station and Code	year	10% actual emerg. DOY	Month-Day		Tlow Deg. C.	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.44	10.00	10.56	11.11
					Deg. F.	42	43	44	45	46	47	48	49	50	51	52
Columbus	1981	150	05-30-81		DDs (F):	1058.1	987.1	918.9	853.4	790.8	731.6	676	623.5	573.7	526.3	481.3
(COLUMOH)	1982	143	05-23-82			980.6	922.9	867.9	815.4	765.3	717.3	671.5	627.8	586	546.2	507.9
	1983	156	06-05-83			1088.7	1013.1	941.2	872.7	807.5	745.3	685.6	628.6	574.5	523.3	474.8
From Fig. 1 – Note high initial emergence June 3 1981 with no prior catch indicate potential missing data or bias and potential earlier emergence; try a) adjust date earlier by 3 days to May 30, b) eliminate this year from analysis. Favor option a) due to a period of high temps (Tmax range 77-84 during week prior to May 27th) so temps were favorable prior to this time and earlier initial emergence was likely but missed. Fig 3 (Akers and Nielsen) non-linearity supports this idea.																
Wooster	1981	148	05-28-81			1009.2	940.2	874	810.5	749.9	692.7	639.1	588.6	540.8	495.4	452.4
(WOOSTERC	1982	145	05-26-82			1051.4	990.7	932.7	877.2	824.1	773.1	724.3	677.6	632.8	590	548.7
	1983	159	06-08-83			1153.7	1075	1000.2	928.7	860.5	795.3	732.5	672.7	615.9	562.1	511
1981 and 1983: similar interpretation as Columbus 1981; assume late estimate due to missed observations, adjust both dates to 3 or 4 days earlier																
Cleveland	1981	154	06-03-81			973.4	905.1	840.3	778.3	719.4	663.2	610	559.7	512.3	467.6	425.6
(CLEVEL2OH	1983	161	06-10-83			996.1	919.6	847.2	778.4	713.2	652	594	539.5	488.6	441.3	397.4
suspect lake effect underestimated by PRISM – use warmer Cleveland rather than Painsville data																
Cincinnati	1982	139	05-19-82			1021.6	959.8	900.9	844.6	790.6	738.9	689.6	642.4	597.4	554.5	513.6
(CINCINNOH)																
Wooster	1979	154	06-05-79			993.9	925.2	859	795.6	735.1	677.6	623.1	571.8	523.3	477.6	434.7
	1980	156	06-06-80			971.1	905.6	843.3	783.8	727.3	673.5	622.3	573.4	527.2	483.5	442.5
Wooster	1998	142	05-22-98			1000.2	931.6	865.7	803.2	743.8	687.4	633.9	582.9	534.1	487.6	443.7
(WOOSTEROH)	source:	https://kb.osu.edu/bitstream/handle/1811/71908/OARDC_special_circular_n165.pdf?sequence=1#page=79														
(assume first emerg 4 days earlier than 10% emerg)																
Results for Columbus and Wooster				avg		1057.0	988.2	922.5	859.7	799.7	742.6	688.2	636.5	587.3	540.6	496.0
1981-1983 only:				sd		60.8	54.3	48.7	44.0	40.2	37.3	35.0	33.5	32.9	33.1	33.8
				cv		5.8	5.5	5.3	5.1	5.0	5.0	5.1	5.3	5.6	6.1	6.8
Results including all data:				avg		1024.8	956.3	890.9	828.5	769.0	712.3	658.5	607.4	558.9	513.0	469.5
				sd		54.5	51.3	48.9	47.2	46.0	45.3	44.8	44.5	44.4	44.4	44.3
				cv		5.3	5.4	5.5	5.7	6.0	6.4	6.8	7.3	8.0	8.7	9.4

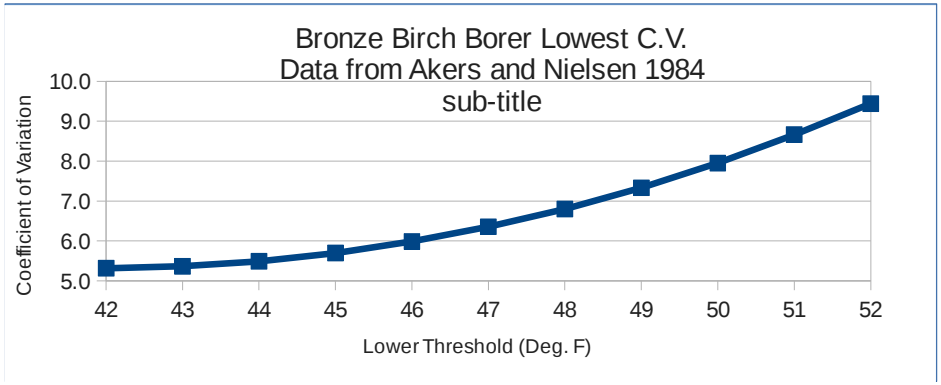


Fig. 1. Lowest C.V. determination for 10% BBB emergence using data from Table 2 above.

Results: When all data locations and years are included, the C.V. value continues to drop with Tlow before beginning to level off at 42-44F. At 43F, the C.V. is 5.3 versus 6.8 at 48F and 8.0 at 50F. These results indicate that a lower Tlow such as 43F may improve predictive power slightly versus 48 or 50F. Generally, lower Tlow values can accommodate more robust models including regions at lower latitudes where warmer Spring weather occurs. At a Tlow of 43F (6.1C), an average of 956 DDF (531 DDC) are required for 10% adult emergence (range: 905-1075 DDF).

Another rationale for using 43F rather than 48 or 50F: sources: https://www.thespruce.com/twelve-species-cultivars-of-birch-trees-3269660
https://www.thespruce.com/twelve-species-of-ash-trees-3269661

Birch growing zones 1 to 9 avg ca. 5 – temperate to very cold temperate regions
Ash growing zones 2 to 9 avg ca. 7 – includes warmer growing regions so emerald ash borer may have a higher lower developmental threshold than bronze birch borer

Emerald ash borer (EAB) has been studied more extensively than BBB and has a Tlow of 50F (which should be re-examined); it may be possible that as a more cold adapted species, BBB would have a lower Tlow than EAB.

Source #2: Muilenburg, VL and DA Herms, 2012. A review of bronze birch borer (Coleoptera: Buprestidae) life history, ecology, and management. Env. Entomol. 41:1372-1385.

Fig. 2. Phenology of bronze birch borer (A. anxius) adult emergence at Midland, MI from 1986 to 1989. Emergence was ...

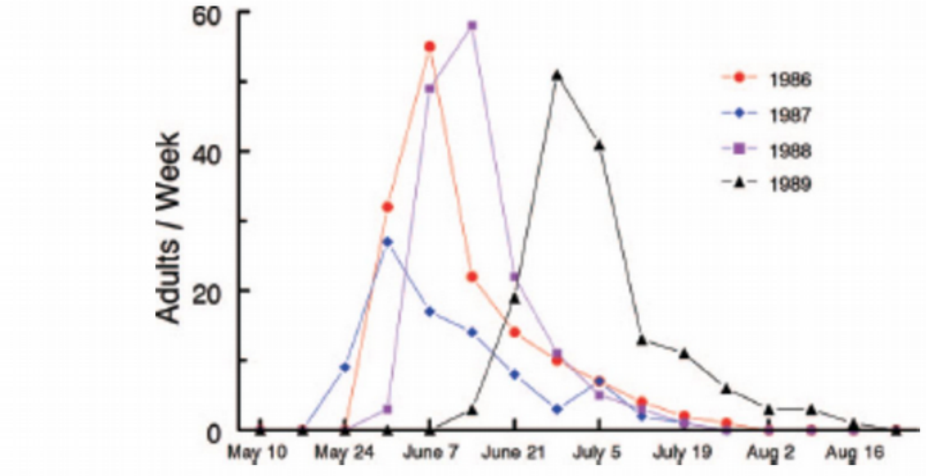


Fig. 2. Phenology of BBB adult emergence at Midland, MI from 1986-1989 (Muilenburg and Herms 2012) – based on appearance of new emergence holes

Methods: Re-analyze Fig. 2 data using:

1. Use Webplotdigitizer tool, https://automeris.io/WebPlotDigitizer/ – to extract data from Fig. 2
2. Convert data to cumulative emergence (separate spreadsheet page available on request). See Fig. 3 below.
3. Use DD calculator for PRISM data for MIDLANDMI to convert x-axis from dates to degree-days at 2 lower thresholds (48F and 43F).
4. Linearize the data using standard methods including a) use Log base 10 (DDs) and b) use logit transformation (+6) for % emergence (Fig 4 below shown for 43F)

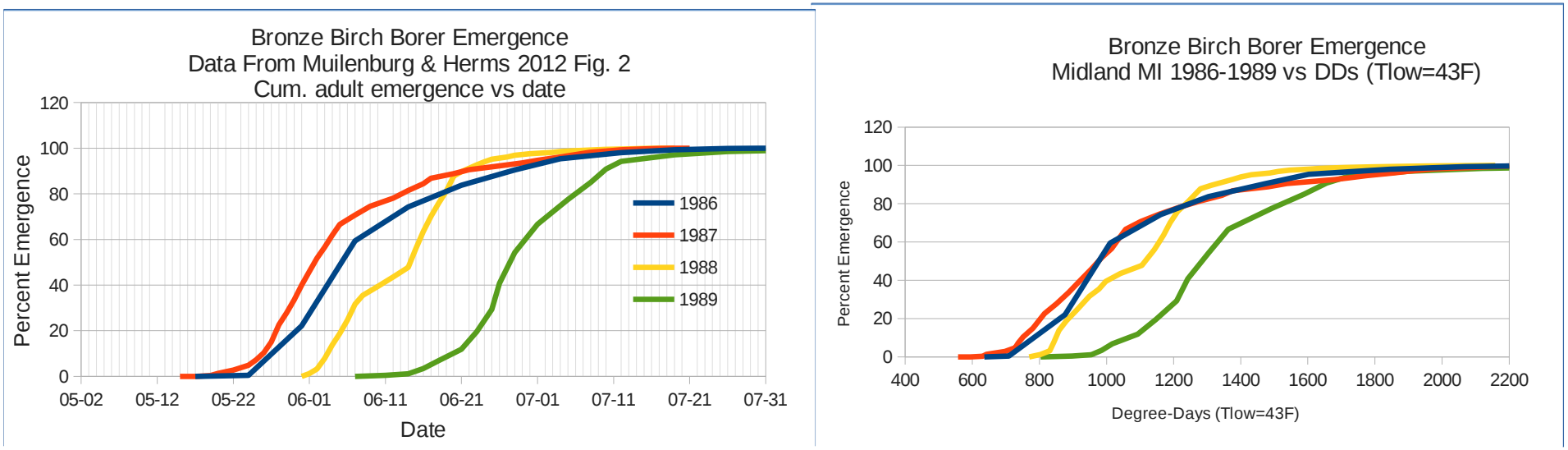
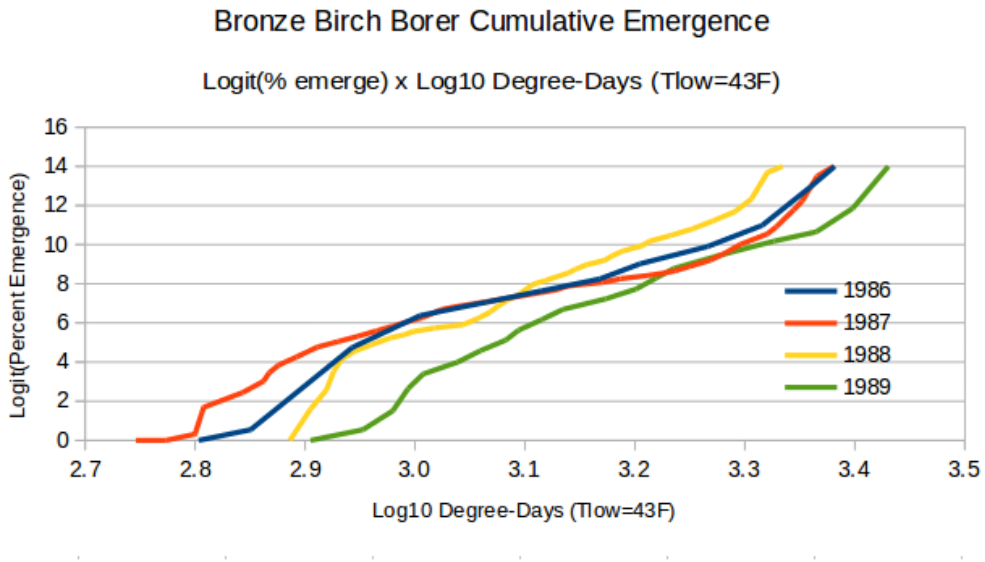


Fig. 3. Convert data from Fig. 2 (Muilenburg and Herms 2012) to cumulative percent versus date (left) and DDs (right). Used to determine first (ca 1%), 10% (comparable to Akers and Nielsen data, source #1 above), 50% and 90% emergence dates. See Table 3 below for lowest C.V. estimation of Tlow.



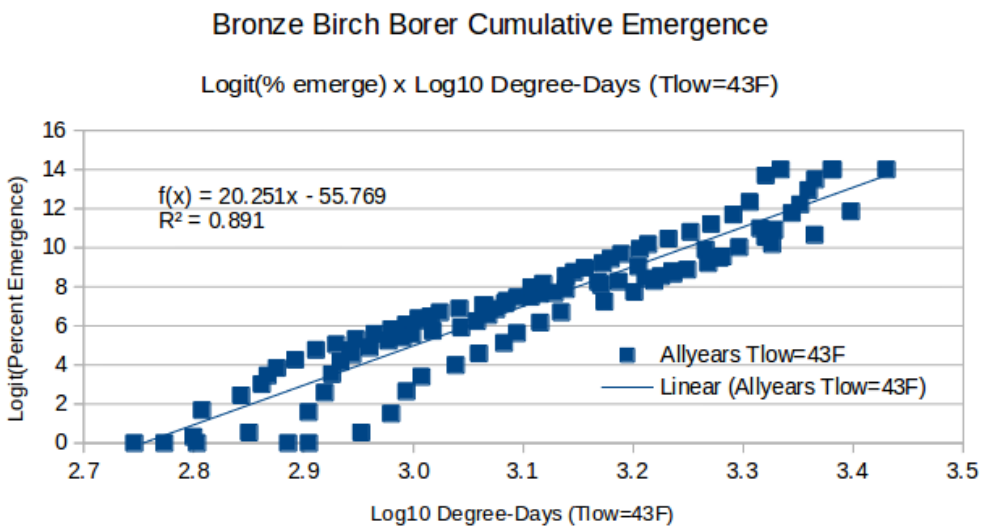


Fig. 4. Linearization of data in Fig. 3 shown above for top: years kept separate and bottom: years combined with regression line.

Table 3. Lowest C.V. comparison of lower developmental thresholds 48, 45, and 43F, for first, 10%, 50%, and 90% emergence based on Fig. 2 of Muilenburg and Herms (2012). Degree-days calculated from PRISM data and batch calculator tool described under source #1 above

Weather station code: MIDLANDMI		Approx. First emerg.	DD Tlow=48F	Approx. 10% emerg.	DD Tlow=48F	Approx. 50% emerg.	DD Tlow=48F	Approx. 90% emerg.	DD Tlow=48F
	1986	05/28/86	540	06/01/86	637	06/07/86	719	07/11/86	1364
	1987	05/20/87	435	05/26/87	515	06/02/87	713	06/25/87	1241
	1988	05/30/88	508	06/05/88	622	06/15/88	839	06/23/88	1033
	1989	06/14/89	672	06/22/89	796	06/28/89	951	07/12/89	1296
avg			538.8		642.5		805.5		1233.5
std			99.1		115.9		113.0		142.8
CV			18.4		18.0		14.0		11.6

		Approx. First emerg.	DD Tlow=45F	Approx. 10% emerg.	DD Tlow=45F	Approx. 50% emerg.	DD Tlow=45F	Approx. 90% emerg.	DD Tlow=45F
	1986	05/28/86	679	06/01/86	788	06/07/86	886	07/11/86	1630
	1987	05/20/87	553	05/26/87	650	06/02/87	870	06/25/87	1465
	1988	05/30/88	638	06/05/88	769	06/15/88	1013	06/23/88	1231
	1989	06/14/89	834	06/22/89	981	06/28/89	1155	07/12/89	1542
avg			676.0		797.0		981.0		1467.0
std			117.7		137.0		132.5		171.2
CV			17.4		17.2		13.5		11.7

	Approx. First emerg.	DD Tlow=43F	Approx. 10% emerg.	DD Tlow=43F	Approx. 50% emerg.	DD Tlow=43F	Approx. 90% emerg.	DD Tlow=43F
1986	05/28/86	785	06/01/86	902	06/07/86	1011	07/11/86	1823
1987	05/20/87	642	05/26/87	751	06/02/87	985	06/25/87	1626
1988	05/30/88	738	06/05/88	880	06/15/88	1143	06/23/88	1376
1989	06/14/89	954	06/22/89	1118	06/28/89	1304	07/12/89	1719
avg		779.8		912.8		1110.8		1636.0
std		130.5		152.2		146.2		191.1
CV		16.7		16.7		13.2		11.7

Results: For approximate first, 10%, and 50% emergence, the Tlow=43F has slightly lower C.V. values than using a Tlow of 45 or 48F. The degree-day average for 10% emerge (913 DDF) is slightly lower than, but within range of, the value of 956 DDF obtained from Akers and Nielsen (see source #1 above).

Source #3: Mussey, G. J.; Potter, D. A. 1997. Phenological correlations between flowering plants and activity of urban landscape pests in Kentucky. Journal of Econ. Entomol. 90:1615-1627. **https://www.sampforestpest.ento.vt.edu/miscellaneous/pdf/mussy-potter1997-misc.pdf**

Methods: Use PRISM data for Lexington KY 1992-94 to test Tlow lowest C.V. values. Not sure if we should assume first emergence or peak activity assoc. with plant phenology (3-yr avg date: May 22). Most likely assume "first activity" to be approximately equivalent to 10% emergence used by sources #1 and #2 above. A rationale for this assumption is that these are more casual observations of adults; not the daily monitoring for exit holes as was reported for sources #1 and #2 above.

Table 4. Lowest C.V. for first activity of bronze birch borer adult emergence, station LEXINGTKY, avg date May 22, 1992-94.

		Degree-days						
	Date	Tlow=42F	Tlow=43F	Tlow=44F	Tlow=45F	Tlow=46F	Tlow=47F	Tlow=48F
1992	05/22/92	1218.8	1136.3	1057.6	983.4	913.2	846.1	782.6
1993	05/22/93	1111.4	1035.6	963.4	894.5	828.8	766	706.1
1994	05/22/94	1086	1010.8	938.3	868.4	801.6	738.2	678
avg		1138.7	1060.9	986.4	915.4	847.9	783.4	722.2
std		70.5	66.5	62.9	60.3	58.2	56.0	54.1
CV		6.2	6.3	6.4	6.6	6.9	7.2	7.5

Results: Assuming that this source is using first or early period activity (and data are not as well documented as source #1 or 2) then this result, from a state further south (KY), appears to be in overall agreement with results above, and that a Tlow of 43F is also a good choice with less error than a higher 48F threshold.

Source #4: Purdue Extension publication: **https://extension.entm.purdue.edu/publications/E-50/E-50.html**

Life Cycle (assume region of Purdue, W. Lafayette Indiana)

- adults found crawling on sunny side of trunk during late May and early June; fly when black locust trees bloom
- eggs hatch in 2 weeks or less, larvae tunnel immediately into the phloem tissue to construct galleries
- one or two years to complete life cycle, larvae pupate in the xylem in late April or early May

Methods: Interpolate approximate dates of events and use PRISM estimated data station name: WLAFAYIN to estimate degree-days for Tlow= 43 and 48F.

Table 5. Average degree-days and C.V. values (compare Tlow=48F and 43F) for approximate events in BBB life cycle in Indiana (PRISM data station name: WLAFAYIN)

		Approximate Date				
approx		**04-24**	**05-10**	**05-25**	**06-03**	**06-12**
event:		**early pupate**	**late pupate**	**early adult**	**mid adult**	**late adult**
Year		**Degree-Days (Tlow=48 Tupper=100F)**				
	2010	348.7	534	744	990	1204
	2011	220.8	364	623	793	1049
	2012	547.8	768	1017	1238	1420
	2013	183.4	395	652	820	996
	2014	153.3	329	523	756	934
	2015	198.7	401	618	781	994
avg		275	465	696	896	1100
std		150	164	172	187	182
CV		54	35	25	21	17
		Degree-Days (Tlow=43 Tupper=100F)				
	2010	506	760	1044	1335	1594
	2011	358	569	899	1114	1414
	2012	774	1062	1383	1648	1875
	2013	300	584	906	1116	1338
	2014	252	502	762	1040	1262
	2015	322	586	871	1079	1336
avg		419	677	978	1222	1470
std		194	207	218	233	229
CV		46	31	22	19	16

Results: 1) A Tlow of 43F produces C.V. values lower than for a Tlow of 48F **(**keep in mind how coarse these data are**)**

2) C.V. values are very high overall and are higher for early events than later events.

3) Approx. events in DDF for early pupation, late pupation, early adult, mid adult, and late adult are estimated as: 419, 677, 978, 1222, and 1470 DDF **(**Tlow=43F**)**

4) Good correspondence with Akers and Nielsen estimates, "early adult" is approx. equivalent to "10% adult emergence", avg 978 DD vs avg 952 DD F (Tlow=43F)

Source #5. Herms DA (2003) A biological calendar for predicting pest activity: six years of plant and insect phenology in Secrest Arboretum, pp.40-49.
In: J.A. Chatfield, J.F. Boggs, E.A. Draper, and P.J. Bennett (eds.), Ornamental plants: annual reports and research reviews 2002. Ohio Agricultural Research Development Center and The Ohio State University Extension Special Circular 189.
https://kb.osu.edu/bitstream/handle/1811/71934/1/OARDC_special_circular_n189.pdf#page=42

- first emergence of adults coincides with blooming of sweetbay magnolia, Magnolia virginiana and with black locust, Robinia pseudoacacia
From Table 1: Bronze birch borer adult emergence: 1997-2002 Avg date: 28-May, Earliest date: 18-May, Latest date: 12-Jun. 2002 date: 2-Jun

Methods: Calculate DDF base 43 for years represented in the table entry. Determine which year was likely the early year and late years in this range.

Table 6. Estimated degree-days (Tlow=43) for a range of dates noted for BBB adult emergence observed between 1997 and 2002 in Wooster, OH.

	Date			
approx. emerge event	**05-18 earliest**	**05-28 average**	**06-12 latest**	**06-02 emerge 2002 only**
	Degree-Days (Tlow=43 Tupper=100F)			
1997	459	587	865	
1998	841	1054	1339	
1999	701	854	1290	
2000	765	933	1247	
2001	672	828	1069	
2002	664	775	1147	903
avg		839		

Results: For adult emergence, both 2002 only with 903 DDF and average over 1997-2002 with 839 DDF (TLow=43F) correspond to other results fairly well.
The early year may have been 1998 (warmest year) and the latest year may have been 1997 (coolest year).

Source #6: Bronze birch borer. The Morton Arboretum (Lisle, IL near Naperville and Chicago IL)
https://www.mortonarb.org/trees-plants/tree-and-plant-advice/help-pests/bronze-birch-borer

Life cycle notes:
1 generation per year
- adults lay eggs in late May or June
- eggs hatch in about 10 days
- larvae feed by tunneling on interior tissue of bark until fall, then form a cell at the end of a tunnel where they overwinter
- larvae pupate the following spring
- adults feed on foliage for about a week before laying eggs

Methods: Estimate the period between adult emergence and egg hatch is ca. 7 days plus 10 days = 17 days during late May and June
Use PRISM data station named: LISLEIL for recent years (2012-2017) to esimate degree days for typical intervals.

Table 7. Estimated period for adult feeding and egg development for bronze birch borer for discriptive observations near Chicago, IL.

Year	DDs (Tlow=43F) May 20-Jun 6	DDs (Tlow=43F) Jun 3—Jun 20
2012	426	511
2013	369	405
2014	445	459
2015	343	463
2016	469	494
2017	345	543
average:	400	479

Results: Estimate ca. 400 to 480 DDF (Tlow=43) between adult exit and egg hatch. Use average of 450 DDF

Table 8. Combined results from all sources above

Source #		1	2	3	4	5		overall
Authors:		Akers & Nielsen 1984	Muilenburg & Herms 2012	Mussy & Potter	Purdue Extension	Herms 2003		averages
Location		various Ohio	Midland, Michigan	Lexington, Kentucky	W. Lafayette, Indiana	Wooster, Ohio		
Approx. latitude		39.1 to 41.7	43.6	38	40.4	40.7		
Event				Degree-Days (Tlow=43F)				
early pupate	average				419			419
	N (site-years)				6			
late pupate	average				677			677
	N (site-years)				6			
1st Emerge	average		779.8					780
	C.V.		16.7					
ca. 10%	average	956.3	912.8	1060.9	978	839		949
emerge	min	905.1	751	1010.8				
	max	1075	1118	1136.3				
	N (site-years)	12	4	3	6	6		
	C.V.	5.4	16.7	6.3	22	0		
ca. 50%	average		1110.8					1111
emerge	C.V.		13.2					
ca. 90%	average		1636.0		1470			1553
emerge	C.V.		11.7		16			

Table 9. Current estimates for a degree-day model for Bronze birch borer from sources above:

Parameter	Deg. F.	Deg. C.
Lower Threshold	43	6.1
Upper Threshold	100	37.8
Event:	**DDs (F)**	**DDs (C)**
Prepupal larvae in overwintering cells in bark	250	139
Beginning of pupation	400	222
End of pupation	700	389
First adults exit trees	750	417
10% adult emergence	950	528
50% adult emergence	1100	611
Beginning of egg hatch and larval tunneling	1400	778
90% adult emergence	1600	889
Adult activity and egg hatch ended, larvae continue tunneling	2050	1139

Validation Section – find and evaluate independent data including pubs, citizen science data, etc., websites including USA NPN, iNaturalist, CERIS Pest Tracker, and Bugwood Wiki. Currently, of these, data available from iNaturalist only.

Source #1: **iNaturalist** **https://www.inaturalist.org/** A science app for sharing and verifying observations in nature

Methods: Compare all reports that appear valid (confirmed by others and have legible photos that match reference materials) with uspest.org model predictions using nearest weather stations.

	Observation Data			Model Data			
Obs. #	**Location**	**Date**	**Stage**	**Nearby Weather Station**	**Nearest Event**	**Date**	**Relevance**
1	https://www.inaturalist.org/observations/6609085						
	Edina, MN	06/12/17	Adult	E3700 Minneapolis, MN	50% Adult Emerg.	06/13/17	Obs. in accord with model prediction
2	https://www.inaturalist.org/observations/34308243						
	Medina, MN	06/12/18	Adult	C6928 Plymouth, MN	50% Adult Emerg.	06/11/18	Obs. in accord with model prediction
3	https://www.inaturalist.org/observations/28398084						
	Benton, NH	07/07/19	Adult	NHLRV Lost River, NH	10% Adult Emergence	07/07/19	Obs. in accord with model prediction
4	https://www.inaturalist.org/observations/26090896						
	Brooklyn, NY	05/30/19	Adult	KJRB Manhattan, NY	50% Adult Emerg.	05/29/19	Obs. in accord with model prediction
5	https://www.inaturalist.org/observations/9092221						
	Minnetonka, MN	05/15/14	Adult	C5102 Minnetonka, MN	10% Adult Emergence	05/13/14	Obs. in accord with model prediction
6	https://www.inaturalist.org/observations/7151234						
	Duluth, MN	06/21/08	Adult	MN082 Duluth, MN	90% Adult Emergence	07/26/08	Obs. in accord with model prediction
7	https://www.inaturalist.org/observations/6468180						
	Brattleboro, VT	06/02/17	Adult	BBOV1 Brattleboro, VT	10% Adult Emergence	06/11/17	Obs. in accord with model prediction (but close to est. of 1st emerg. Of 5/31/17)
8	https://www.inaturalist.org/observations/3415672						
	Omaha, NE	06/04/16	Adult	D9161 Bellevue, NE	90% Adult Emergence	06/09/16	Obs. in accord with model prediction

Results : All 8 available observations from 5 states are within the range for adult emergence predicted by the model, and thus help to validate the model.

Discussion: Further validation data are needed, preferably these would be research quality monitoring of appearance of new exit holes over the duration of adult emergence, from more than one state, especially near edges of this insects' distribution.